Magnetic Field Strength of Straight Wire and Solenoid

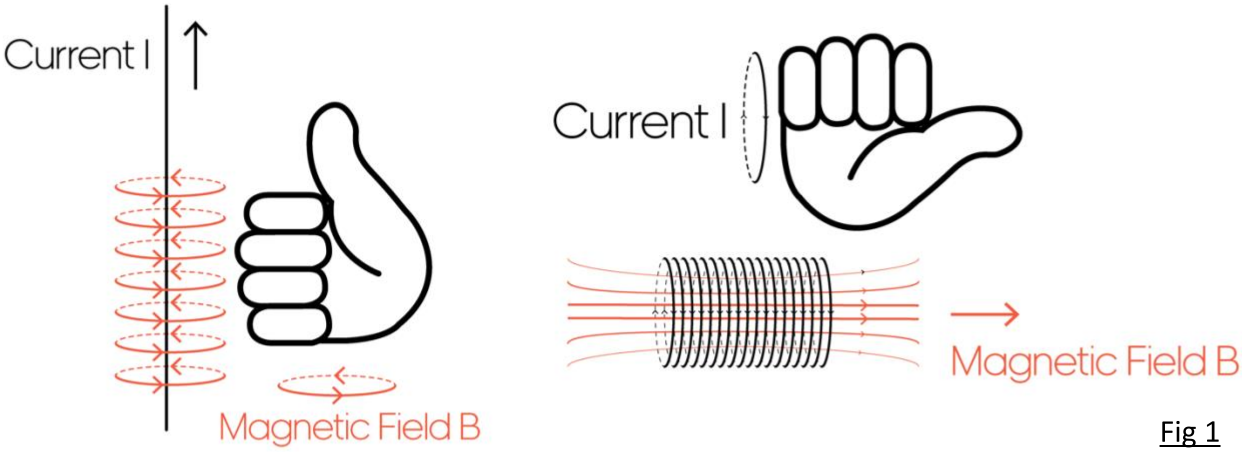

Fig 1

Purpose

Using mobile device with "AP-Sensor" app as magnetometer to investigate the magnetic field strength of a long straight wire and a solenoid with electric current flowing in it.

Theory

- Magnetic field is generated by moving charges, expressed by magnetic field lines. The closer the adjacent field lines, the stronger is the field, and vice versa.
- For a long straight conducting wire, the magnetic field strength generated by a current *I* flowing in it is given by $B = \frac{\mu_0 I}{2\pi r}$, where μ_0 is the permeability of free space and its value is 4.0 x 10^{-7} TmA^{-1}, *I* is the current generated by the moving charges, *r* is the radial distance from the wire. For fixed amount of current *I*, the relationship between *B* and *r* can be investigated. For fixed distance *r*, the effect of current *I* on *B* can be studied (Fig 2).
- Given that an "infinitely long" wire is used in the experiment, i.e. length of wire ℓ is very large compared to the distance between the wire and the magnetometer *r* ($\ell \gg r$), the stray magnetic field at the ends of wire can be neglected. The magnetic field is generated in coaxial direction around the wire which is inversely proportional to the radial distance from the wire *r*. Using right-hang grip rule, when the thumb points to the direction of current flow, the remaining four fingers indicate the direction of magnetic field induced by the current (Fig 1).
- For a solenoid with N turns in a length *L*, the magnetic field strength generated by a current *I* flowing in it is given by $B = \frac{\mu_0 N I}{L}$. For fixed amount of current *I*, the relationship between *B* and number of turns per unit length *N/L* can be investigated. For fixed number of turns per unit length, the effect of current *I* on *B* can be studied (Fig 3).
- The iron core is used in the solenoid that makes the magnetic field stronger.

- The magnetic field is uniform, i.e. it is the same everywhere, inside the solenoid. The magnetic field outside the solenoid resembles that of a permanent magnet, diverging at one end and converging at another end, determined by right-hand grip rule (Fig 1).
- The SI unit of magnetic field strength is Tesla (T). The unit used in this experiment is μT (10^{-6}T).
- A resistor with suitable resistance must be included in the circuit to prevent short circuit. Resistors with different resistance can also be used for experimentation with different current.
- The ammeter is connected to take the reading of current in the unit of Ampere (A).
- The "AP-Sensor" app utilizes the built-in magnetometer in your mobile device to measure the surrounding magnetic field strength.
- By the principle of superposition, the resultant magnetic field is the sum of the background "stray" (unwanted) magnetic field and the magnetic field generated by the wire and solenoid. The background magnetic field will be assessed in order to reduce the error in the study.

Apparatus

- Mobile device with "AP-Sensor" app
- A long straight wire
- A solenoid
- A low-voltage D.C. electricity supply
- An ammeter
- A ruler
- Resistors with different resistance

Setup

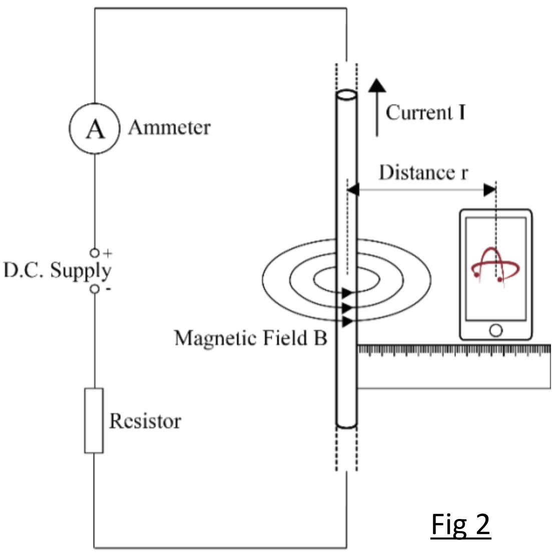

Fig 2

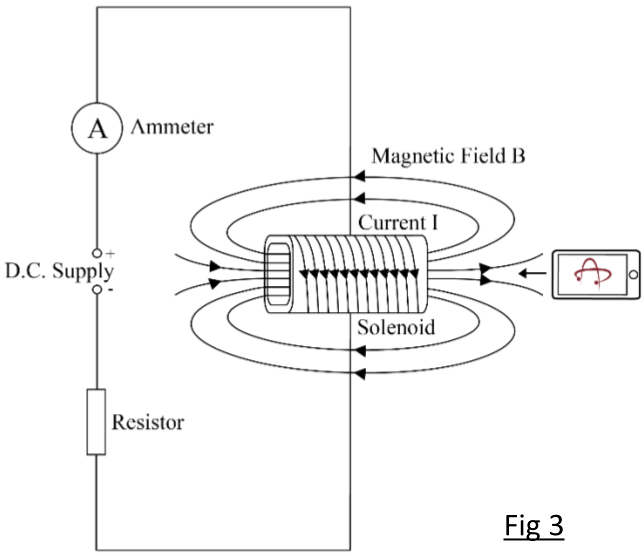

Fig 3

Procedure

Set up the Experiment

1. Set up the circuit as shown in Fig 2.
2. Run the app "AP-Sensor". In the "Experiment" tab, press "B-Field Vs Distance" to start this experiment.
3. Place the mobile device to the middle part of the wire.

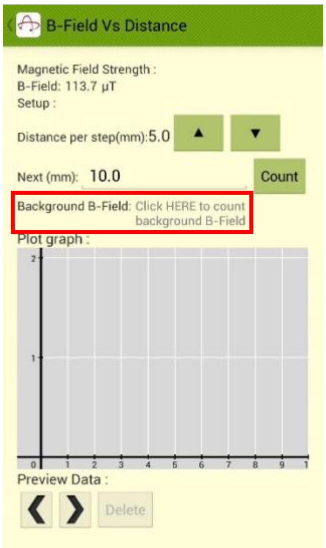

Fig 4

Remove Background "Stray" Magnetic Field

4. When the D.C. supply is turned off, press the "Click HERE to count background B-Field" button to found background magnetic field (Fig 4). The background magnetic field will be shown in the field, and eliminated in the measured B-Field. The background magnetic field can be reset by pressing the button again (Fig 5).

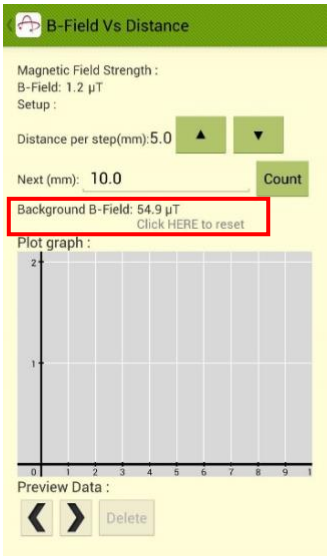

Fig 5

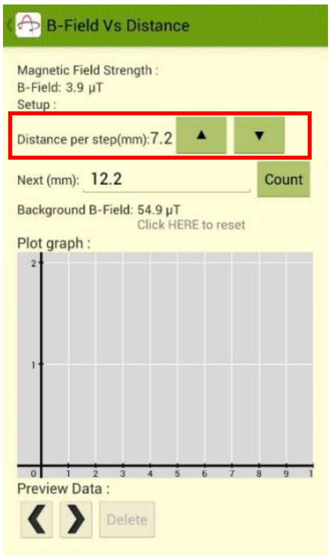

Fig 6

Fig 7

Part 1. Testing for Long Straight Wire

5. Press the "Up/Down Arrow" to increase/decrease the "Distance per step" by 0.1mm (Fig 6). It depends on your preference on data resolution. For your reference, it is suggested to set "Distance per step" to 5.0mm on order to observe the significant trend at reasonable resolution.
6. The initial step is 5.0mm by default. Assume the magnetometer lies at the centre of the mobile device. Measure the half length of the short edge of the mobile device. Type the initial distance between the magnet and the magnetometer directly in the field "Next" (Fig 7). (You may or may not start at the closest distance. For strong magnetic field, the device should be kept a certain distance away from the device to avoid damaging the electronic components.)
7. Turn on the D.C. power supply. Record the current *I* in the circuit from the ammeter.
8. Press "Count" to record data at that distance and plot the point on the graph. The app will automatically be ready for counting the next data point.

9. Move the mobile device along the ruler at corresponding distances. Tap “Count” to take data at each point. Repeat this step until sufficient data points are collected.
10. The data will be shown in graph and in “Preview Data” table. Desired data point, shown as red, can be selected by pressing the “Left/Right Arrow”. Undesired data point can be chosen and deleted by pressing “Delete” button. Note that the “Delete” action is irreversible. In Fig 9, the 2nd data point from Fig 8 is deleted.

    Note: If further data will be recorded, remember to reset “Next” after deleting the data.
11. Copy the data and plot a graph of magnetic field strength against the reciprocal of distance (1/r).
12. At a fixed distance *r*, repeat Step 6 to 10 for different current *I*. The current can be controlled by changing the voltage of the power supply (if available), or by replacing a resistor with different resistance.

Fig 8

Fig 9

Part 2. Testing for Solenoid

13. Set up the circuit as shown in Fig 3. Record the number of turns per unit length of the solenoid.
14. Place the mobile device at the middle part inside the solenoid.
15. When the D.C. supply is turned off, press the “Click HERE to count background B-Field” button to found background magnetic field.
16. Turn on the D.C. power supply. Record the current *I* in the circuit from the ammeter.
17. Press “Count” to record data for several points inside the solenoid and observe the pattern. Record the results.
18. At a fixed point inside the solenoid, repeat and record the measurement for different current *I*. The current can be controlled by changing the voltage of the power supply (if available), or by replacing a resistor with different resistance.
19. For the same current, repeat the measurement for solenoid with different number of turns per unit length *N/L*. Record the data.

Data

Part 1.1 Magnetic Field of Long Straight Wire at Different Distance

Background Magnetic Field = ___________

Current *I* = ___________

Distance *r* (m)	Reciprocal of Distance 1/*r* (m^{-1})	Magnetic Field Strength *B* (T)

Plot a graph of magnetic field strength *B* against the reciprocal of distance 1/*r*.

Part 1.2 Magnetic Field of Long Straight Wire with Different Current

Distance *r* = ____________

Current *I* (A)	Magnetic Field Strength *B* (T)

Plot a graph of magnetic field strength *B* against the current *I*.

Part 2.1 Magnetic Field of Solenoid with Different Current

Background Magnetic Field = ___________

Number of Turns of Solenoid (*N*) = ___________

Length of Solenoid (*L*) = ___________

Number of Turns Per Unit Length (*N/L*) = ___________

Current *I* (A)	Magnetic Field Strength *B* (T)

Plot a graph of magnetic field strength *B* against the current *I*.

Part 2.2 Magnetic Field of Solenoid with Different Number of Turns Per Unit Length

Current *I* = ____________

Number of Turns	Length of Solenoid (m)	Number of Turns Per Unit Length (m^{-1})	Magnetic Field Strength *B* (T)

Plot a graph of magnetic field strength *B* against the number of turns per unit length *N/L*.

Discussion

1. What are the sources of background magnetic field? Are they significant to the experiment?
2. For long straight wire, what is the relationship of the magnetic field strength against the distance *r*, and against the current *I*?
3. For solenoid, what is the relationship of the magnetic field strength against the current *I*, and against number of turns per unit length *N/L*?
4. How does the magnetic field vary inside different position of the solenoid?
5. From the slope of the graphs above, you can determine the experimental value of permeability in free space μ_0. What is the value? Compare your experimental value with the theoretical value.
6. What are the possible errors of the experiment? How can we improve to reduce the errors?